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Interim Report on the Investigation of the Fresh Properties of Synthetic Fiber-Reinforced Concrete for the Richardson Landing Casting Field

Wendy R. Long, Kirk E. Walker, and Brian H. Green

April 2017



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Interim Report on the Investigation of the Fresh Properties of Synthetic Fiber-Reinforced Concrete for the Richardson Landing Casting Field

Wendy R. Long, Kirk E. Walker, and Brian H. Green

*Geotechnical and Structures Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199*

Final report

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Prepared for Delwick Warfield, P.E.
Construction Branch (EC-C)
U.S. Army Engineer District, Memphis
167 North Main Street, Rm B-202
Memphis, TN 38103-1894

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Abstract

The U.S. Army Engineer District, Memphis uses the Richardson Landing mat casting field to produce articulated concrete mats that are tied together to form articulated concrete revetment “blankets” that are then placed on the riverbanks to serve as a form of erosion control. The Memphis District noted that the corners of some of these concrete mats were becoming damaged as the mats were moved from the casting field to the construction site. To combat this issue, the Memphis District, Construction Branch, decided to incorporate synthetic fibers in the current concrete mixture proportion to bridge cracks induced by moving the concrete mats. However, there was concern that the addition of fibers would significantly reduce the workability of the concrete mixture, making it labor intensive to place in the forms and difficult to discharge the fresh concrete from transport vehicles at the casting field.

The Memphis District contracted with the U. S. Army Engineer Research and Development Center’s (ERDC’s) Concrete and Materials Branch (CMB) to proportion three fiber-reinforced concrete mixtures containing 3-, 2-, and 1-lb(s)/yd³, respectively, of synthetic (polypropylene) fiber into the current mixture proportion used at Richardson Landing mat casting field. The CMB performed aggregate testing, concrete trial batching, and hardened concrete strength testing to produce the new concrete mixture proportions. This interim report presents the results of testing conducted by the CMB as of 30 August 2016.

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Contents

Abstract	ii
Figures and Tables.....	iv
Preface	v
Unit Conversion Factors	vi
1 Introduction.....	1
2 Aggregate Testing Results.....	3
3 Mixture Proportioning.....	7
4 Project Delivery Team	13
4.1 Financial.....	13
4.2 Administration.....	13
4.3 Technical contact information.....	14
4.4 Financial contact information	14
References	15
Appendix A: Materials Information	16
Report Documentation Page	

Figures and Tables

Figures

Figure 1. Gradation of #57 crushed limestone from the Cumberland Quarry, Pine Bluff Sand and Gravel.....	4
Figure 2. ASTM (2011) (C40) organic impurities testing of dredged sand.	6

Tables

Table 1. ASTM (2006) (C136) gradations for #57 crushed limestone from the Cumberland Quarry, Pine Bluff Sand and Gravel (cumulative % passing).....	3
Table 2. ASTM (2015a) (C127), bulk specific gravity and absorption of #57 crushed limestone from the Cumberland Quarry, Pine Bluff Sand and Gravel (material retained on No. 4 sieve).	4
Table 3. ASTM (2006) (C136) gradations for dredged fine aggregate (cumulative % passing).	5
Table 4. ASTM (2015b) (C128), bulk specific gravity and absorption of dredged fine aggregate.....	5
Table 5. Concrete mixture proportions for mixture no. 169-16 RLM-T6.....	8
Table 6. Concrete mixture proportions for mixture no. 169-16 RLM-T5.....	9
Table 7. Concrete mixture proportions for mixture no. 158-16 RLM-T3.....	10
Table 8. Concrete mixture proportions for mixture no. 146-16 RLM-T2.....	11
Table 9. Concrete mixture proportions for mixture no. 145-16 RLM-T1.....	12

Preface

This study was conducted for the U.S. Army Engineer District, Memphis-Construction Branch under MIPR No. W38XGR60986322 dated 7 April 2016.

The work was performed by the Concrete and Materials Branch (CMB) of the Engineering Systems and Materials Division (ESMD), Geotechnical and Structures Laboratory (GSL), U. S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. At the time of publication, Christopher M. Moore was Chief, CMB; Dr. Gordon W. McMahon was Chief, ESMD; and Dr. Pamela G. Kinnebrew was the Technical Director for Military Engineering. The Deputy Director of ERDC-GSL was Dr. William P. Grogan, and the Director was Bart P. Durst.

COL Bryan S. Green was the Commander of ERDC, and Dr. David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
ounces (U.S. fluid)	2.957353 E-05	cubic meters
pints (U.S. liquid)	0.473176	liters
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic inch	2.757990 E+04	kilograms per cubic meter
quarts (U.S. liquid)	9.463529 E-04	cubic meters
square inches	6.4516 E-04	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

1 Introduction

The U.S. Army Corps of Engineers (USACE), Memphis District, uses the Richardson Landing mat casting field to produce the articulated concrete mats that are tied together to form articulated concrete revetment “blankets” that are placed on riverbanks to maintain the desired bank alignment and configuration and serve as a form of erosion control. The casting field has an established concrete mixture proportion that they use to produce the mats, and this proportion has undergone few changes during the last decade.

After the concrete mats are produced at the casting field, they are moved several times before they are placed on the riverbank. During the process of moving the mats, some breakage of the corners of the individual mats has been observed. In an effort to mitigate corner breakage of the concrete mats, the Memphis District has decided to incorporate synthetic fibers at a rate of up to 3 lb/yd³ into the concrete mixture proportion to see if these fibers can help reduce corner breakage.

The Memphis District, Construction Branch, is concerned that the addition of conventional construction-grade synthetic fibers will significantly reduce the workability of the concrete mixture, which is typically quantified by the slump test. A reduction in workability would make the concrete more labor intensive to finish and place. It could also make it more difficult to effectively discharge the fresh concrete into the mat forms from the fresh concrete transport devices at the casting field.

The Memphis District-Construction Branch requested that the Concrete and Materials Branch (CMB) of the U.S. Army Engineer Research and Development Center (ERDC) modify the current concrete mixture proportion and incorporate synthetic fibers while maintaining the target 3-to4-in. slump and 3,000 psi compressive strength at 90-days age.

The concrete mixture proportion used in this study is similar to the one used to produce the articulated concrete mats in 2010 at the Richardson Landing mat casting field. The concrete mixture proportion was adjusted to incorporate synthetic (polypropylene) fibers at dosage rates of 1-lb, 2-lb, and 3-lb / yd³. Since the fiber content is already built into this year’s

construction contract and the contractor has already selected the fiber, no additional testing to characterize the impact of the fiber content on the mechanical performance of the concrete was conducted.

The Memphis District-Construction Branch requested that the concrete mixture proportions include a 0.650 water-to-cementitious ratio, 25 percent fly ash by volume of cementitious material, and 300 to 500 lb/yd³ of cementitious material. The target air content for this project was 4.0 to 7.0 percent (ASTM International 2014) (C231), and the target compressive strength was a minimum of 3,000 psi at 90 days (ASTM International 2016c) (C39).

The operating contractor at Richardson Landing sampled the constituent materials that are currently being used to produce concrete at the casting field and shipped the materials to the CMB laboratory facility in Vicksburg, MS.

Mill certificates and admixture data sheets for the materials used were supplied by the Memphis District Construction Branch, and can be found in Appendix A.

2 Aggregate Testing Results

The ASTM International (2006) (C136) gradation results for the coarse limestone aggregate are presented in Table 1. The results of Run 1 and Run 2 were much finer than the data that the Memphis District-Construction Branch had provided, so an additional two aggregate samples were tested a few weeks later. The results of Runs 3 and 4 were even finer than Runs 1 and 2 and struggled to meet the ASTM International C33 criteria for a #57 stone. Each of these gradations along with the ASTM International (2016b) (C33) gradation limits for a #57 stone are shown in Figure 1.

The bulk specific gravity at the saturated, surface-dry condition was comparable to the specific gravity provided in historical data for this aggregate as shown in Table 2. However, the absorption measured by the ERDC-CMB was lower than the historical data.

Table 1. ASTM (2006) (C136) gradations for #57 crushed limestone from the Cumberland Quarry, Pine Bluff Sand and Gravel (cumulative % passing).

Sieve Size	Gradation Testing by CMB, Cumulative % Passing					Historical Gradation Provided ¹ By Memphis District
	Run 1	Run 2	Run 3	Run 4	CMB Average	
1 1/2 in.	100.0	100.0	100.0	100.0	100.0	100
1 in.	98.0	98.5	98.0	98.5	98.3	98
3/4 in.	81.6	86.3	87.9	91.2	86.8	72
1/2 in.	44.2	51.0	59.2	63.3	54.4	34
3/8 in.	25.1	31.3	37.8	41.1	33.8	15
No. 4	7.3	8.4	9.5	10.7	9.0	3
No. 8	4.6	4.8	5.0	5.5	5.0	2
No. 200 (ASTM C117)	2.9	3.0	3.1	3.3	3.1	1.8

¹Data from materials reports provided by USACE Memphis District-Construction Branch (Appendix A).

Figure 1. Gradation of #57 crushed limestone from the Cumberland Quarry, Pine Bluff Sand and Gravel.

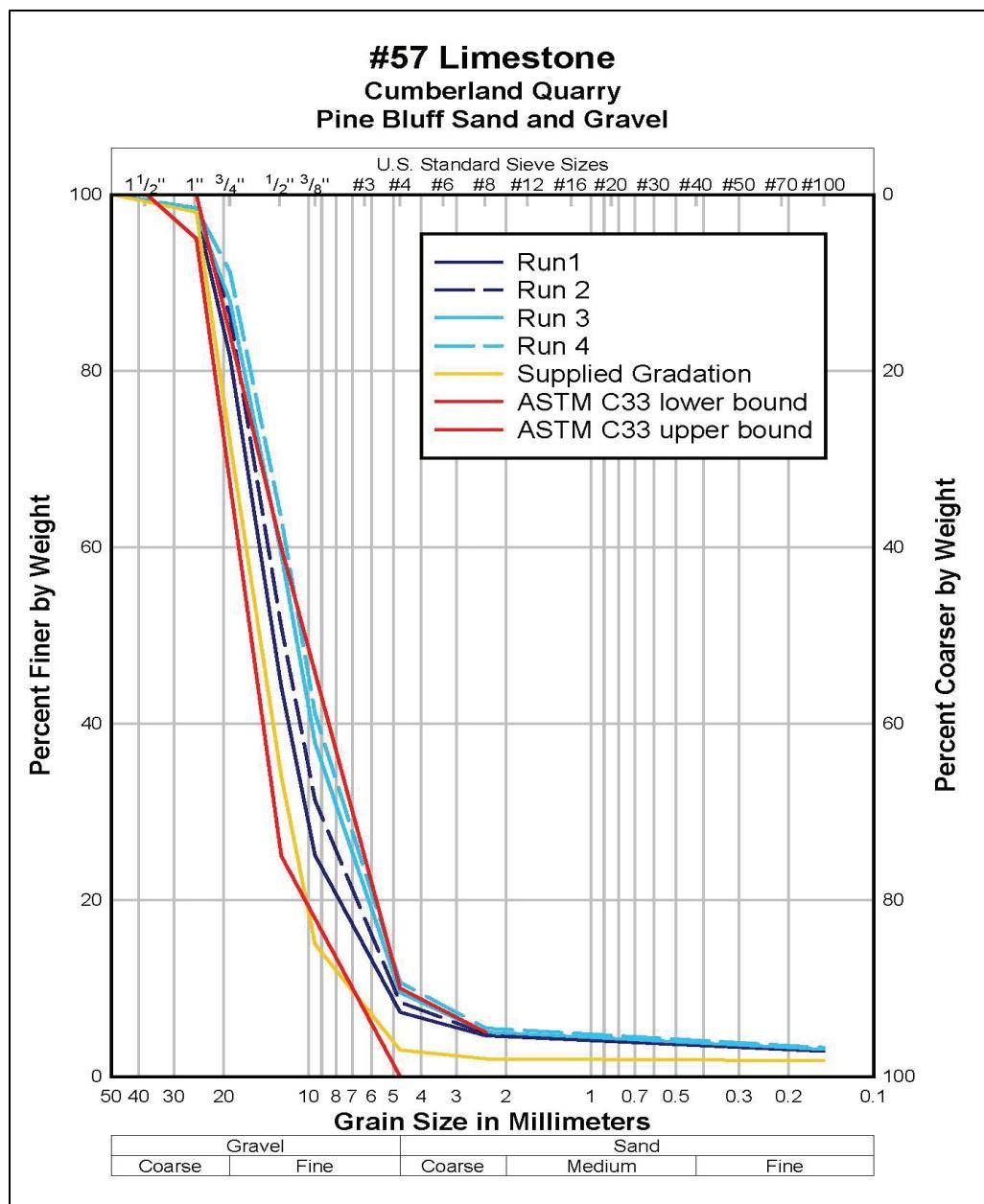


Table 2. ASTM (2015a) (C127), bulk specific gravity and absorption of #57 crushed limestone from the Cumberland Quarry, Pine Bluff Sand and Gravel (material retained on No. 4 sieve).

Property	Testing by CMB					Historical Data Provided ¹ By Memphis District
	Run 1	Run 2	Run 3	Run 4	Average	
Bulk specific gravity (SSD)	2.696	2.693	2.682	2.685	2.689	2.669
Absorption, %	0.69	0.82	0.91	0.93	0.84	1.2

¹Data from materials reports provided by USACE Memphis District-Construction Branch (Appendix A).

The fine aggregate used for this project is a dredged, natural river sand sourced from Mississippi River at Mile 769.2 AHP (Above Head of Passes). The gradation, absorption, and specific gravity results for this material are at Tables 3 and 4.

Table 3. ASTM (2006) (C136) gradations for dredged fine aggregate (cumulative % passing).

Sieve Size	Gradation Testing by CMB, Cumulative % Passing		
	Run 1	Run 2	Average
3/8 in.	99.6	98.9	99
No. 4	98.1	95.6	97
No. 8	92.3	89.4	91
No. 16	75.4	73.7	75
No. 30	45.5	44.9	45
No. 40	25.4	25.2	25
No. 50	13.1	13.0	13
No. 100	1.5	1.6	1.6
No. 200	0.6	0.6	0.6
No. 200 (ASTM 2013b (C117)	0.6	0.6	0.6

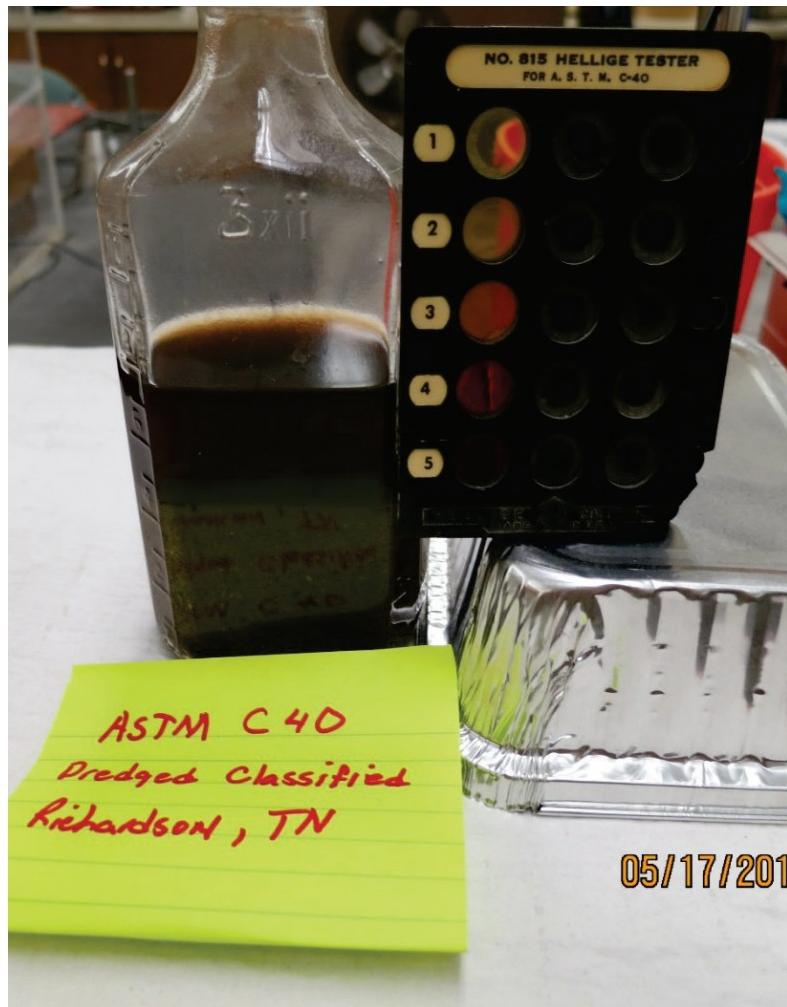
Table 4. ASTM (2015b) (C128), bulk specific gravity and absorption of dredged fine aggregate.

Property	Run 1	Run 2	Average	Historical Data Provided¹ By Memphis District
Bulk specific gravity (SSD)	2.64	2.64	2.64	2.62
Absorption	0.49%	0.48%	0.49%	0.80%

¹Data from materials reports provided by USACE Memphis District-Construction Branch (Appendix A).

The fine aggregate had an unusually dark color when tested in accordance with ASTM International (2011) (C40). The ASTM C40 organic impurity color was reported as a 4. Aggregates with this dark of a color may have problems with air entrainment, freeze thaw durability, and compressive strength due to organic impurities being present in the fine aggregate. Problems with air entrainment were not observed during the trial batching process, and the Memphis District has indicated that this fine aggregate has not caused problems with the concrete produced in the field. Figure 2 shows the results of the ASTM C40 test.

Figure 2. ASTM (2011) (C40) organic impurities testing of dredged sand.



3 Mixture Proportioning

Concrete mixture proportioning trial batches of 1.5 cu ft each were produced using the CMB laboratory's 5.0-cu ft capacity Gilson Mixer. Standard laboratory mixing procedures were followed in accordance with ASTM International (2016a) (C192). Six trial batches were produced and five of the six are reported in this Interim Report. Trial Batch 4 is not reported because it did not meet the project requirements. The concrete mixture proportions, mixture characteristics, materials used, and test results for each of the mixtures are documented at Table 5 through Table 9.

Trial Batch 1 (Table 9) and Trial Batch 2 (Table 8) did not include fibers and are included in this report for information purposes only. These two mixtures are beyond the original scope of this project, but help show the effects of chemical admixture and fiber dosages.

Trial Batch 1 (Table 9) had a lower slump and air content than is allowable for this project. To improve these fresh properties, more air-entraining admixture was added to Trial Batch 2 (Table 8).

Trial Batch 2 (Table 8) has the same admixture dosage as Trial Batch 3 (Table 7). Trial Batch 3 included a fiber dosage rate of 1 lb of fiber/ yd³. However, the addition of 1 lb of fiber/ yd³ in Trial Batch 3 reduced the slump from 6.0 in. (Trial Batch 2) to 3.0 in.

Table 5. Concrete mixture proportions for mixture no. 169-16 RLM-T6.

Table 6. Concrete mixture proportions for mixture no. 169-16 RLM-T5.

REPORT OF CONCRETE MIXTURE PROPORTIONS										
Project: FRC for Articulated Concrete Matress				2 lbs. of fiber per cu. yd. mixture						
Proportioned for: USACE Memphis District				Proportioned: 17-Jun-16						
Proportioned by: USACE ERDC-Concrete and Materials Branch				25% Class F fly ash Mixture No. 169-16 RLM-T5						
1. MIXTURE PROPORTIONS										
Material	Aggregate, %		Solid Volume		Mass, S.S.D.		Bulk Sp. Gr.	Absorption,		
	by vol.	by wt.	ft ³	m ³	lb/yd ³	kg/m ³	S.S.D.	%		
Portland cement			1.445	0.054	284	169	3.15			
Fly ash			0.482	0.018	72	43	2.39 ^a			
Fine aggregate	43.0	42.5	8.533	0.316	1406	834	2.64	0.49		
Coarse Aggregate	57.0	57.5	11.312	0.419	1899	1127	2.69	0.76		
Fiber			0.038	0.001	2.1	1.3	0.91 ^a	0.00		
Batch water			3.706	0.137	231	137.3	1.0			
Air Entraining Admixture					3 fl. oz	0.1 Ltrs				
Water-Reducing Admixture					13.6 fl. oz	0.5 Ltrs				
Air			1.485	0.055						
Totals:	100	100.0	27.00	1.000	3894	2311				
2. MIXTURE CHARACTERISTICS										
S/A, % :by volume	43.0%		Theo. Unit Wt., kg/m ³ (lb /ft ³)		2311		145.3			
W/(C+M), by weight:	0.650		Cementitious Factor, kg/m ³ (lb/yd ³):		211		356			
3. TEST RESULTS										
Batch Number	Fresh Properties						Unconfined Compressive Strength, MPa (psi) ^c			
	Slump in.	Air Content %	Air Content ^b %	Unit Weight lb/ft ³	Relative Yield	Temp. °F	7-day ^d	14-Day	28-day	56-day
1	3.50	6.0	5.8	0	0.0%	74.8	3030	3450	4010	4190
4. MATERIALS:										
COARSE AGGREGATE: Crushed limestone, ASTM C33 #57, Cumberland Quarry, Pine Bluff Sand & Gravel; aggregate gradation, specific gravity, and absorption values determined in ERDC-CMB aggregate testing laboratory										
FINE AGGREGATE: Dredged sand from the Mississippi River at Mile 769.2 AHP; aggregate gradation, specific gravity, and absorption values determined in ERDC-CMB aggregate testing laboratory										
CEMENT: Type I/II portland cement, Buzzi Unicem, Festus Plant										
POZZOLANS: Fly ash, class F, Headwaters Resources, Prairie State										
FIBER: Synthetic fiber, Tuf-Strand MaxTen, Euclid Chemical Company, length 3/4-in., polypropylene/polyethylene blend										
ADMIXTURES: AEA-92S, ASTM C260 and CRD C-13 air entraining admixture, Euclid Chemical Company										
WR-91, ASTM C494 Type A water reducer, Euclid Chemical Company										
REMARKS:										
a During trial batching, a specific gravity of 2.39 was used for the fly ash as is reflected in a mill report from 3/14/16. A specific gravity of 0.91 was used for the Tuf-Strand synthetic fibers, as is reflected in the manufacturer's data sheet										
b Aggregate correction factor = 0.2 percent applied										
c Compressive strength tests made on nominal 4 x 8-in. cylinders per ASTM C39										
d Specimens cured at 72°F in 100% relative humidity room per ASTM C192										

Table 7. Concrete mixture proportions for mixture no. 158-16 RLM-T3.

REPORT OF CONCRETE MIXTURE PROPORTIONS											
Project: FRC for Articulated Concrete Matress	1 lbs. of fiber per cu. yd. mixture										
Proportioned for: USACE Memphis District	Proportioned: 06-Jun-16										
Proportioned by: USACE ERDC-Concrete and Materials Branch	25% Class F fly ash Mixture No. 158-16 RLM-T3										
1. MIXTURE PROPORTIONS											
Material	Aggregate, %		Solid Volume		Mass, S.S.D.		Bulk Sp. Gr.				
	by vol.	by wt.	ft ³	m ³	lb/yd ³	kg/m ³	S.S.D.				
Portland cement			1.445	0.054	284	169	3.15				
Fly ash			0.482	0.018	72	43	2.39 ^a				
Fine aggregate	43.0	42.5	8.542	0.316	1407	835	2.64				
Coarse Aggregate	57.0	57.5	11.323	0.419	1901	1128	2.69				
Fiber			0.018	0.001	1.0	0.6	0.91 ^a				
Batch water			3.706	0.137	231	137.3	1.0				
Air Entraining Admixture					3 fl. oz	0.1 Ltrs					
Water-Reducing Admixture					10.6 fl. oz	0.4 Ltrs					
Air			1.485	0.055							
Totals:	100	100.0	27.00	1.000	3896	2312					
2. MIXTURE CHARACTERISTICS											
S/A, % :by volume	43.0%		Theo. Unit Wt., kg/m ³ (lb./ft ³)		2312		145.5				
W/(C+M), by weight:	0.650		Cementitious Factor, kg/m ³ (lb./yd ³):		211		356				
3. TEST RESULTS											
Batch Number	Fresh Properties						Unconfined Compressive Strength, MPa (psi) ^c				
	Slump in.	Air Content %	Air Content ^b %	Unit Weight lb./ft ³	Relative Yield	Temp. °F	7-day ^d	14-Day	28-day	56-day	
1	3.00	5.8	5.6	0	0.0%	74.4	2970	3520	3960	4310	
4. MATERIALS:											
COARSE AGGREGATE: Crushed limestone, ASTM C33 #57, Cumberland Quarry, Pine Bluff Sand & Gravel; aggregate gradation, specific gravity, and absorption values determined in ERDC-CMB aggregate testing laboratory											
FINE AGGREGATE: Dredged sand from the Mississippi River at Mile 769.2 AHP; aggregate gradation, specific gravity, and absorption values determined in ERDC-CMB aggregate testing laboratory											
CEMENT: Type I/II portland cement, Buzzi Unicem, Festus Plant											
POZZOLANS: Fly ash, class F, Headwaters Resources, Prairie State											
FIBER: Synthetic fiber, Tuf-Strand MaxTen, Euclid Chemical Company, length 3/4-in., polypropylene/polyethylene blend											
ADMIXTURES: AEA-92S, ASTM C260 and CRD C-13 air entraining admixture, Euclid Chemical Company											
WR-91, ASTM C494 Type A water reducer, Euclid Chemical Company											
REMARKS:											
a During trial batching, a specific gravity of 2.39 was used for the fly ash as is reflected in a mill report from 3/14/16. a specific gravity of 0.91 was used for the Tuf-Strand synthetic fibers, as is reflected in the manufacturer's data sheet											
b Aggregate correction factor = 0.2 percent applied											
c Compressive strength tests made on nominal 4 x 8-in. cylinders per ASTM C39											
d Specimens cured at 72°F in 100% relative humidity room per ASTM C199											

Table 8. Concrete mixture proportions for mixture no. 146-16 RLM-T2.

REPORT OF CONCRETE MIXTURE PROPORTIONS											
Project: FRC for Articulated Concrete Matress				No Fiber Mix							
Proportioned for: USACE Memphis District				Proportioned: 25-May-16							
Proportioned by: USACE ERDC-Concrete and Materials Branch				25% Class F fly ash							
				Mixture No. 146-16 RLM-T2							
1. MIXTURE PROPORTIONS											
Material	Aggregate, %		Solid Volume		Mass, S.S.D.		Bulk Sp. Gr.				
	by vol.	by wt.	ft ³	m ³	lb/yd ³	kg/m ³	S.S.D.				
Portland cement			1.445	0.054	284	169	3.15				
Fly ash			0.482	0.018	72	43	2.39 ^a				
Fine aggregate	43.0	42.5	8.550	0.317	1409	836	2.64				
Coarse Aggregate	57.0	57.5	11.333	0.420	1903	1129	2.69				
							0.76				
Batch water			3.706	0.137	231	137.3	1.0				
Air Entraining Admixture					3 fl. oz	0.1 Ltrs					
Water-Reducing Admixture					10.6 fl. oz	0.4 Ltrs					
Air			1.485	0.055							
Totals:	100	100.0	27.00	1.000	3898	2314					
2. MIXTURE CHARACTERISTICS											
S/A, % :by volume	43.0%		Theo. Unit Wt., kg/m ³ (lb /ft ³)		2314		145.6				
W/(C+M), by weight:	0.650		Cementitious Factor, kg/m ³ (lb/yd ³):		211		356				
3. TEST RESULTS											
Batch Number	Fresh Properties						Unconfined Compressive Strength, MPa (psi) ^c				
	Slump in.	Air Content %	Air Content ^b %	Unit Weight lb/ft ³	Relative Yield	Temp. °F	7-day ^d	14-Day	28-day	56-day	
1	6.00	5.9	5.7	142.4	97.8%	74.5	2430	3060	3380	#DIV/0!	
4. MATERIALS:											
COARSE AGGREGATE: Crushed limestone, ASTM C33 #57, Cumberland Quarry, Pine Bluff Sand & Gravel; aggregate gradation, specific gravity, and absorption values determined in ERDC-CMB aggregate testing laboratory											
FINE AGGREGATE: Dredged sand from the Mississippi River at Mile 769.2 AHP; aggregate gradation, specific gravity, and absorption values determined in ERDC-CMB aggregate testing laboratory											
CEMENT: Type I/II portland cement, Buzzi Unicem, Festus Plant											
POZZOLANS: Fly ash, class F, Headwaters Resources, Prairie State											
ADMIXTURES: AEA-92S, ASTM C260 and CRD C-13 air entraining admixture, Euclid Chemical Company											
WR-91, ASTM C494 Type A water reducer, Euclid Chemical Company											
REMARKS:											
a During trial batching, a specific gravity of 2.39 was used for the fly ash as is reflected in a mill report from 3/14/16.											
b Aggregate correction factor = 0.2 percent applied											
c Compressive strength tests made on nominal 4 x 8-in. cylinders per ASTM C39											
d Specimens cured at 72°F in 100% relative humidity room per ASTM C192											

Table 9. Concrete mixture proportions for mixture no. 145-16 RLM-T1.

REPORT OF CONCRETE MIXTURE PROPORTIONS											
No Fiber Mix											
Project: FRC for Articulated Concrete Matress				Proportioned: 24-May-16							
Proportioned for: USACE Memphis District				25% Class F fly ash							
Proportioned by: USACE ERDC-Concrete and Materials Branch				Mixture No. 145-16 RLM-T1							
1. MIXTURE PROPORTIONS											
Material	Aggregate, %		Solid Volume		Mass, S.S.D.		Bulk Sp. Gr.				
	by vol.	by wt.	ft ³	m ³	lb/yd ³	kg/m ³	S.S.D.				
Portland cement			1.445	0.054	284	169	3.15				
Fly ash			0.482	0.018	72	43	2.39 ^a				
Fine aggregate	43.0	42.5	8.550	0.317	1409	836	2.64				
Coarse Aggregate	57.0	57.5	11.333	0.420	1903	1129	2.69				
Batch water			3.706	0.137	231	137.3	1.0				
Air Entraining Admixture					1.7 fl. oz	0.1 Ltrs					
Water-Reducing Admixture					10.6 fl. oz	0.4 Ltrs					
Air			1.485	0.055							
Totals:	100	100.0	27.00	1.000	3898	2314					
2. MIXTURE CHARACTERISTICS											
S/A, % :by volume	43.0%		Theo. Unit Wt., kg/m ³ (lb/ft ³)		2314		146.3				
W/(C+M), by weight:	0.650		Cementitious Factor, kg/m ³ (lb/yd ³):		211		356				
3. TEST RESULTS											
Batch Number	Fresh Properties						Unconfined Compressive Strength, MPa (psi) ^c				
	Slump in.	Air Content %	Air Content ^b %	Unit Weight lb/ft ³	Relative Yield	Temp. °F	7-day ^d	14-Day	28-day	56-day	
1	2.25	4.5	4.3	146	99.8%	71.8	2900	3620	4170	#DIV/0!	
4. MATERIALS:											
COARSE AGGREGATE: Crushed limestone, ASTM C33 #57, Cumberland Quarry, Pine Bluff Sand & Gravel; aggregate gradation, specific gravity, and absorption values determined in ERDC-CMB aggregate testing laboratory											
FINE AGGREGATE: Dredged sand from the Mississippi River at Mile 769.2 AHP; aggregate gradation, specific gravity, and absorption values determined in ERDC-CMB aggregate testing laboratory											
CEMENT: Type I/II portland cement, Buzzi Unicem, Festus Plant											
POZZOLANS: Fly ash, class F, Headwaters Resources, Prairie State											
ADMIXTURES: AEA-92S, ASTM C260 and CRD C-13 air entraining admixture, Euclid Chemical Company											
WR-91, ASTM C494 Type A water reducer, Euclid Chemical Company											
REMARKS:											
a During trial batching, a specific gravity of 2.39 was used for the fly ash as is reflected in a mill report from 3/14/16.											
b Aggregate correction factor = 0.2 percent applied											
c Compressive strength tests made on nominal 4 x 8-in. cylinders per ASTM C39											
d Specimens cured at 72°F in 100% relative humidity room per ASTM C192											

4 Project Delivery Team

Brian Green
601.634.3216
Brian.H.Green@usace.army.mil

Research geologist, Concrete and Materials Branch
CEERD-GM-C

Wendy Long
601.634.3238
Wendy.R.Long@usace.army.mil

Research civil engineer, Concrete and Materials Branch
CEERD-GM-C

Kirk Walker
601.634.3237
Kirk.E.Walker@usace.army.mil

Engineering technician, Concrete and Materials Branch
CEERD-GM-C

4.1 Financial

Alicia Souza-Pope (ERDC-MIO)
601.634.4372
Alicia.A.Souza-Pope@usace.army.mil

Budget technician, Management Integration Office
CEERD-GZ-M

4.2 Administration

Sherrie Johnson
601.634.3276
Sherrie.E.Johnson@usace.army.mil

Administrative assistant, Concrete and Materials Branch
CEERD-GM-C

Christopher Moore
601.634.3271
Christopher.Moore@usace.army.mil
Chief, Concrete and Materials Branch
CEERD-GM-C

4.3 Technical contact information

Brian H. Green
U.S. Army Engineer R&D Center
CEERD-GM-C
Building 6000
3909 Halls Ferry Road Vicksburg, MS 39180
Phone: 601.634.3216
Brian.H.Green@usace.army.mil

4.4 Financial contact information

Alicia Souza-Pope
U. S. Army Engineer R&D Center
CEERD-GZ-M
Building 6000
3909 Halls Ferry Road
Vicksburg, MS 39180
Phone: 601-634-4372
Alicia.A.Souza-Pope@usace.army.mil

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- _____. 2016a. *Standard practice for making and curing concrete teste specimens in the laboratory*. Designation C192-16. Philadelphia, PA: ASTM International.
- _____. 2016b. *Standard specification for concrete aggregates*. Designation C33-16. Philadelphia, PA: ASTM International.
- _____. 2016c. *Standard test method for compressive strength of concrete specimens*. Designation C39-16a. Philadelphia, PA: ASTM International.

Appendix A: Materials Information

Mill certificates and admixture data sheets for the materials used were supplied by the U.S. Army Engineer District, Memphis, Construction Branch.

 Buzzi Unicem USA MILL CERTIFICATION REPORT PORTLAND CEMENT - TYPE I/II LOW ALKALI			
Certification date: 3/9/2016 Cement Type: I/II Low Alkali Laboratory: Festus Plant			
<p>We hereby certify that this cement complies with current ASTM C150 and AASHTO M85 Specifications The following data represents the average for the Buzzi Unicem USA cement that was produced in the month of FEBRUARY 2016</p>			
ASTM STANDARD REQUIREMENTS		MILL CERTIFICATION VALUES	
CHEMICAL DATA C150			
SiO ₂ - %	*	SiO ₂ - %	18.98
Al ₂ O ₃ - %	max 6.0	Al ₂ O ₃ - %	4.95
Fe ₂ O ₃ - %	max 6.0	Fe ₂ O ₃ - %	3.73
CaO - %	*	CaO - %	62.69
MgO - %	max 6.0	MgO - %	2.76
SO ₃ - %	max 3.0***	SO ₃ - %	3.19
Loss on Ignition - %	max 3.0	Loss on Ignition - %	2.65
Insoluble Residue - %	max 0.75	Insoluble Residue - %	0.2
CO ₂ in Cement - %	*	CO ₂ in Cement - %	1.34
Limestone - %	max 5.0	Limestone - %	3.18
CaCO ₃ in Limestone - %	min 70.0	CaCO ₃ in Limestone - %	95.58
Potential Phase Compounds:**		Potential Phase Compounds:**	
C ₃ S - %	*	C ₃ S - %	57.6
C ₂ S - %	*	C ₂ S - %	10.7
C ₃ A - %	max 8	C ₃ A - %	6.8
C ₄ AF - %	*	C ₄ AF - %	11.3
C ₄ AF + 2(C ₃ A) - %	*	C ₄ AF + 2(C ₃ A) - %	24.9
C ₃ S + 4.75C ₃ A - %	max 100	C ₃ S + 4.75C ₃ A - %	89.8
Na ₂ O Equivalent - %	max 0.60	Na ₂ O Equivalent - %	0.39
PHYSICAL DATA C150			
Fineness- Blaine - m ² /kg	min 260	Fineness- Blaine - m ² /kg	383
Autoclave Expansion %	max 0.80	Autoclave Expansion %	0.06
Time of Set		Time of Set	
Vicat (minutes)	min 45	Vicat (minutes)	Initial 81
	max 37.5		Final 191
Air Content %	max 12	Air Content %	7.5
Compressive Strength:		Compressive Strength:	
1 day - psi (MPa)	*	1 day - psi (MPa)	2150 (14.8)
3 day - psi (MPa)	1740 (12.0)	3 day - psi (MPa)	3553 (24.5)
7 day - psi (MPa)	2760 (19.0)	7 day - psi (MPa)	4890 (33.7)
Mortar Bar expansion % (C1038) ***		Mortar Bar expansion % (C1038)	0.012
<u>Nicholas Rice</u> By _____ Quality Control Manager or Quality Supervisor			
<small>* Not applicable</small> <small>** Adjusted per ASTM C150 Annex A1b</small> <small>*** It is permissible to exceed the values for SO₃ content, provided that the Mortar Bar Expansion C1038 does not exceed 0.020 % at 4 days</small>			
BUZZI UNICEM USA, Festus Plant 1000 River Cement Road, Festus, MO 63028-0903, P.O. Box 1003, Phone 636.931.0900			

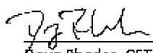


**ASTM C618 / AASHTO M295 Testing of
Prairie State Fly Ash**

Sample Type:	Monthly	Report Date:	3/14/2016		
Sample Date:	1/1 - 1/31/16	MTRF ID:	270PS		
Sample ID:					
Chemical Analysis			ASTM / AASHTO Limits	ASTM Test	
			Class F	Class C	Method
Silicon Dioxide (SiO ₂)	56.75 %				
Aluminum Oxide (Al ₂ O ₃)	18.56 %				
Iron Oxide (Fe ₂ O ₃)	10.04 %				
Sum of Constituents	85.35 %	70.0% min	50.0% min	D4326	
Sulfur Trioxide (SO ₃)	0.93 %	5.0% max	5.0% max	D4326	
Calcium Oxide (CaO)	5.56 %			D4326	
Magnesium Oxide (MgO)	1.47 %				
Sodium Oxide (Na ₂ O)	1.26 %				
Potassium Oxide (K ₂ O)	2.75 %				
Total Alkali as Na ₂ Oeq	3.07 %				
Moisture	0.04 %	3.0% max	3.0% max	C311	
Loss on Ignition	0.50 %	6.0% max	6.0% max	C311	
		5.0% max	5.0% max	AASHTO M295	
Physical Analysis					
Fineness, % retained on #325	19.78 %	34% max	34% max	C311, C430	
Strength Activity Index - 7 or 28 day requirement					
7 day, % of control	78 %	75% min	75% min	C311, C109	
28 day, % of control	88 %	75% min	75% min		
Water Requirement, % control	97 %	105% max	105% max		
Autoclave Soundness	-0.01 %	0.8% max	0.8% max	C311, C151	
Density	2.39			C604	

The strength activity index is not to be considered a measure of the compressive strength of concrete containing the fly ash.

Headwaters Resources certifies that pursuant to current ASTM C618 protocol for testing, the test data listed herein was generated by applicable ASTM methods and meets the requirements of ASTM C618.


 Doug Rhodes, CET
 Facility Manager



Materials Testing & Research Facility
 2650 Old State Highway 113
 Taylorsville, Georgia 30178
 P: 770 684 0102
 F: 770 684 5114
www.headwaters.com

BOWSER-MORNER, INC.

Delivery Address: 4518 Taylorsville Road • Dayton, Ohio 45424 **Mailing Address:** P. O. Box 51 • Dayton, Ohio 45401

AASHTO/ISO 17025 Accredited • USACE Validated



LABORATORY REPORT

Report To: Pine Bluff Sand & Gravel — 2016
 Attn: Mike Nelson
 780 Spencer Road
 Salem, KY 42078

Report Date: November 20, 2015
Job No.: 172312
Report No.: 715891
No. of Pages: 3

Report On: Laboratory Analysis of One No. 57 Crushed Limestone Sample
 Source: Cumberland Quarry

On October 6, 2015, one No. 57 crushed limestone sample was submitted for selected laboratory analysis from the above referenced source. Testing was performed as specified by the client and in accordance with the following procedures:

- ASTM C 29, "Unit Weight and Voids in Aggregate".
- ASTM C 88, "Soundness of Aggregates by Use of Sodium Sulfate".
- ASTM C 117, "Material Finer Than 75- μm (No. 200) Sieve in Mineral Aggregates by Washing".
- ASTM C 127, "Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate".
- ASTM C 131, "Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine".
- ASTM C 136 "Sieve Analysis of Fine and Coarse Aggregates".
- ASTM C 142, "Clay Lumps and Friable Particles in Aggregates".

Results are detailed on the attached data sheet

Should you have any questions, or if we may be of further service, please contact me at (937) 236-8805, extension 322.

Respectfully submitted,
 BOWSER-MORNER, INC.

Karl A. Fletcher, Manager
 Construction Materials and
 Geotechnical Laboratories

KAF/gls/crh
 715891
 1-File
 1-mike.nelson@pbsg.com

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Report To: Pine Bluff Sand & Gravel
 Source: Cumberland Quarry

BMI Job No.: 172312
 BMI Report No.: 715891

Sample ID: No. 57 Crushed Limestone

TABLE I
 Sieve Analysis (ASTM C 136)

Sieve Size	Percent Passing
1 1/2"	100
1"	98
3/4"	72
1/2"	34
3/8"	15
No. 4	3
No. 8	2
No. 200 Decant, %:	1.8

* Gradation Provided By Client

TABLE II
 Summary of Results

Test Parameter	Test Method	Results
Los Angeles Abrasion - Grading B, %:	ASTM C 131	29.6
Sodium Sulfate Soundness, %:	ASTM C 88	7.9
Clay Lumps & Friable Particles, %:	ASTM C 142	0.23
Dry-Rodded Bulk Density, pcf:	ASTM C 29	95.0
Dry-Rodded Bulk Density, tcy:	ASTM C 29	1.282
Loose Bulk Density, pcf:	ASTM C 29	86.4
Loose Bulk Density, tcy:	ASTM C 29	1.166
Bulk Dry Specific Gravity:	ASTM C 127	2.639
Bulk SSD Specific Gravity:	ASTM C 127	2.669
Apparent Specific Gravity:	ASTM C 127	2.722
Absorption, %:	ASTM C 127	1.2

TABLE III
 Five Cycle Sodium Sulfate Soundness (ASTM C 88) - Detailed by Size Fraction

Size Fraction	Percent Loss	Gradation Factor	Weighted Percent Loss
1" to 3/4"	5.91	0.285	1.68
3/4" to 1/2"	6.71	0.379	2.54
1/2" to 3/8"	11.82	0.182	2.15
3/8" to No. 4	9.83	0.154	1.51
Total	---	---	7.9

LEHMAN ROBERTS
COARSE AND FINE AGGREGATE SPECIFIC GRAVITY

COARSE AND FINE AGGREGATE SPECIFIC GRAVITY

AGGREGATE Coarse Sand

DATE 03/22/2016

COARSE AGGREGATE
% OF MIX 0

COARSE AGGREGATE		
% OF MIX		
	TEST 1	TEST 2
WT OF SSD		
WEIGHT IN WATER		
WT. OF OVEN DRY		
BULK SPECIFIC GRAVITY	ERR	ERR
APPARENT SPECIFIC GRAVITY	ERR	ERR
ABSORPTION %	ERR	ERR

FINE AGGREGATE				% OF MIX	100
FLASK A-1265.0g	TEST 1	TEST 2	TEST 3		
FLASK B-1265.6g	A	B	C		
	WT OF SSD	537.2	509.3		
	FLASK+SSD+H ₂ O	988.7	971.6		
	FLASK+H ₂ O	655.2	655.2		
	WEIGHT IN H ₂ O	333.5	316.4	0	
	WT. OF OVEN DRY	533.7	505		
BULK SPECIFIC GRAVITY	2.620	2.618	ERR		
APPARENT SPECIFIC GRAVITY	2.666	2.678	ERR		
ABSORPTION %	0.7	0.9	ERR		

COMBINED BULK SPEC GRAVITY	2.620	2.618	
COMBINED APP'L SPEC GRAVITY	2.666	2.678	
COMBINED ABSORPTION %	0.7	0.9	

AVERAGE BULK SPECIFIC GRAVITY	2.619
AVERAGE APPARENT SPECIFIC GRAVITY	2.672
AVG COMBINED ABSORBTION%	0.8

The Euclid Chemical Company



EUCLID CHEMICAL

EUCON AEA-92S

AIR ENTRAINING AGENT FOR CONCRETE

DESCRIPTION

EUCON AEA-92S is formulated for use as an air entraining admixture for concrete of all types and is manufactured under rigid control which assures uniform and precise performance. It should be added to the mix independently and not with other admixtures.

PRIMARY APPLICATIONS

- Ready mix concrete
- Structural concrete
- Mass concrete
- Paving concrete
- All exterior concrete

FEATURES/BENEFITS

- Provides a stable air void system with proper bubble size and spacing. This air void system protects concrete against damage caused by repeated freeze/thaw cycles
- Concrete is made more resistant to de-icing salts, sulfate attack and corrosive water
- Less mixing water can be used per yard (meter) of concrete and placeability is improved
- Minimizes bleeding and segregation of the concrete

TECHNICAL INFORMATION

EUCON AEA-92S is an aqueous solution compound of organic chemicals. It is compatible with concrete mixes containing other commonly used Euclid Chemical Company admixtures.

PACKAGING

EUCON AEA-92S is packaged in bulk, 275 gal (1041 L) totes, 55 gal (208 L) drums and 5 gal (18.9 L) pails.

SHELF LIFE

2 years in original, unopened package

SPECIFICATIONS/COMPLIANCES

EUCON AEA-92S meets or exceeds the requirements of the following specifications:

- Corps of Engineers Specification CRD C-13
- ASTM Specification C 260
- AASHTO Specification M 154

AIR ENTRAINERS

EUCON AEA-92S

MASTER FORMAT #:
 03 30 00 03 40 00
 03 70 00

DIRECTIONS FOR USE

EUCON AEA-92S is typically dosed at a rate of 0.5 to 2 oz per 100 lbs (30 to 130 mL per 100 kg) of total cementitious material to entrain 3% - 6% air content. The amount of EUCON AEA-92S will vary depending on type of cement, fineness of sand, temperature, design of the mix, other admixtures, etc. Concrete mixes must be tested regularly to confirm that proper air content is achieved. EUCON AEA 92S should be added directly to the sand to achieve maximum performance.

PRECAUTIONS/LIMITATIONS

- Consult your local Euclid Chemical representative for the proper dosage rate adjustments when using fly ash, slag or high range water reducers.
- Add to the mix independent of other admixtures
- In all cases, consult the Safety Data Sheet before use

Rev. 2.15

WARRANTY: The Euclid Chemical Company ("Euclid") solely and expressly warrants that its products shall be free from defects in materials and workmanship for one (1) year from the date of purchase. Unless authorized in writing by an officer of Euclid, no other representations or statements made by Euclid or its representatives, in writing or orally, shall alter this warranty. EUCLID MAKES NO WARRANTIES, IMPLIED OR OTHERWISE, AS TO THE MERCHANTABILITY OR FITNESS FOR ORDINARY OR PARTICULAR PURPOSES OF ITS PRODUCTS AND EXCLUDES THE SAME. If any Euclid product fails to conform with this warranty, Euclid will replace the product at no cost to Buyer. Replacement of any product shall be the sole and exclusive remedy available and buyer shall have no claim for incidental or consequential damages. Any warranty claim must be made within one (1) year from the date of the claimed breach. Euclid does not authorize anyone on its behalf to make any written or oral statements which in any way alter Euclid's installation information or instructions in its product literature or on its packaging labels. Any installation of Euclid products which fails to conform with such installation information or instructions shall void this warranty. Product demonstrations, if any, are done for illustrative purposes only and do not constitute a warranty or warranty alteration of any kind. Buyer shall be solely responsible for determining the suitability of Euclid's products for the Buyer's intended purposes.

The Euclid Chemical Company



EUCLID CHEMICAL

EUCON WR 91

WATER REDUCING, SET RETARDING ADMIXTURE

DESCRIPTION

EUCON WR 91 is a liquid, water-reducing and set retarding admixture for concrete. EUCON WR 91 shows improved setting and finishing characteristics when compared to other commonly used ASTM C 494 Type A water reducers. EUCON WR 91 may be used at a wide range of dosage rates. EUCON WR 91 does not contain calcium chloride or other potential corrosion-enhancing ingredients.

PRIMARY APPLICATIONS

- Flatwork concrete
- General ready mix concrete
- Architectural concrete
- Mass concrete
- Bridge decks
- Hot weather concrete

FEATURES/BENEFITS

Plastic Concrete

- Improves finishability
- Improves workability
- Reduces water requirement
- Reduces segregation
- Improves setting times
- Compatible with air entraining agents

Hardened Concrete

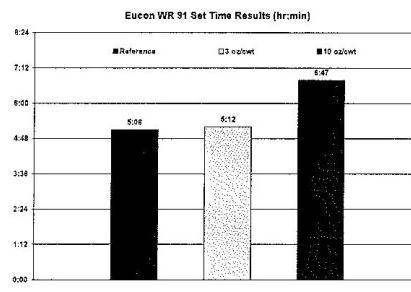
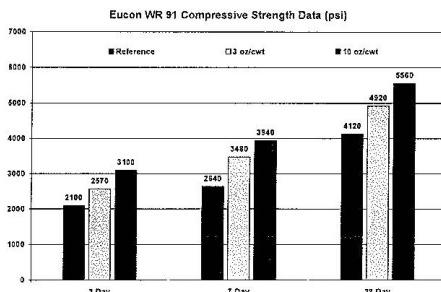
- Increases strength at all ages
- Reduces permeability
- Improves finished appearance
- Reduces cracking
- Increases durability
- Non staining

TECHNICAL INFORMATION

Performance Data

The following test results were achieved using typical ASTM C 494 mix design requirements, 517 lb/yd³ (307 kg/m³) cement content and similar ($\pm 0.5\%$) air content.

These results were obtained under laboratory conditions with materials and mix designs meeting the specifications of ASTM C 494. Changes in materials and mix designs can affect the dosage response of EUCON WR 91.



WATER REDUCERS

EUCON WR 91

MASTER FORMAT #:
03 30 00 03 40 00
03 70 00

PACKAGING

EUCON WR 91 is packaged in bulk, 275 gal (1041 L) totes, 55 gal (208 L) drums, and 5 gal (18.9 L) pails.

SHELF LIFE

1 year in original, unopened container.

SPECIFICATIONS/COMPLIANCES

EUCON WR 91 meets or exceeds the requirements of:

- ASTM C 494, Type A & D
- AASHTO M 194
- ANSI/NSF STD 61

DIRECTIONS FOR USE

EUCON WR 91 is typically used at dosages of 2 to 10 oz per 100 lbs (130 to 650 mL per 100 kg) of cementitious material. Higher dosages are acceptable with prior testing and confirmation of the desired performance with specific materials being used.

EUCON WR 91 should be added to the initial batch water of the concrete mixture. Do not dispense onto dry cement.

PRECAUTIONS/LIMITATIONS

- Care should be taken to maintain EUCON WR 91 above freezing, however, freezing and subsequent thawing will not harm the material if thoroughly agitated.
- Never agitate with air.
- Add to mix independent of other admixtures.
- In all cases, consult the Safety Data Sheet before use.

Rev. 11.14

WARRANTY: The Euclid Chemical Company ("Euclid") solely and expressly warrants that its products shall be free from defects in materials and workmanship for one (1) year from the date of purchase. Unless authorized in writing by an officer of Euclid, no other representations or statements made by Euclid or its representatives, in writing or orally, shall alter this warranty. EUCLID MAKES NO WARRANTIES, IMPLIED OR OTHERWISE, AS TO THE MERCHANTABILITY OR FITNESS FOR ORDINARY OR PARTICULAR PURPOSES OF ITS PRODUCTS AND EXCLUDES THE SAME. If any Euclid product fails to conform with this warranty, Euclid will replace the product at no cost to Buyer. Replacement of any product shall be the sole and exclusive remedy available and buyer shall have no claim for incidental or consequential damages. Any warranty claim must be made within one (1) year from the date of the claimed breach. Euclid does not authorize anyone on its behalf to make any written or oral statements which in any way alter Euclid's installation information or instructions in its product literature or on its packaging labels. Any installation of Euclid products which fails to conform with such installation information or instructions shall void this warranty. Product demonstrations, if any, are done for illustrative purposes only and do not constitute a warranty or warranty alteration of any kind. Buyer shall be solely responsible for determining the suitability of Euclid's products for the Buyer's intended purposes.

The Euclid Chemical Company



EUCLID CHEMICAL

TUF-STRAND MAXTen™

MACRO SYNTHETIC FIBER

DESCRIPTION

TUF-STRAND MAXTen is a macro synthetic fiber successfully used as an alternate to steel fibers and welded wire mesh in a wide variety of secondary reinforcement applications. TUF-STRAND MaxTen fibers comply with ASTM C1116, Standard Specification for Fiber Reinforced Concrete and Shotcrete, and are specifically used for the reduction of plastic shrinkage cracks, to improve impact, shatter and abrasion resistance, to increase fatigue resistance, to increase toughness of concrete and provide long term durability of concrete and cement based building products. Dosage rates will vary depending upon the reinforcing requirements and can range typically from 3.0 to 5.0 lbs/yd³ (1.8 to 3.0 kg/m³). TUF-STRAND MaxTen synthetic macro-fibers comply with applicable portions of the International Code Council (ICC) Acceptance Criteria AC32 for synthetic fibers and can save time and money on construction projects by eliminating the purchase, storage, handling, cutting, placing and waste of welded wire mesh. These fibers are chemically inert and will not corrode.

PRIMARY APPLICATIONS

- Industrial and residential floors
- Whitetoppings, bridge decks and pavements
- Thin walled pre-cast (septic tanks, vaults, walls, etc.)
- Mass concrete

FEATURES/BENEFITS

- Increases impact, shatter and abrasion resistance of concrete
- Reduces segregation, plastic settlement, and shrinkage cracking of concrete
- Provides three-dimensional reinforcement against micro and macro-cracking
- Increases overall durability, fatigue resistance and flexural toughness
- Reduction of in-place cost versus wire mesh for temperature / shrinkage crack control
- Easily added to concrete mixture at any time prior to placement
- Tested in accordance with ASTM C 1399 and C 1609 (formerly C 1018)

TECHNICAL INFORMATION

Typical Engineering Data

Material	polypropylene/polyethylene blend	Melt Point	320°F (160°C)
Specific Gravity	0.91	Electrical and Thermal Conductivity	low
Typical Dosage Rates	3 to 5 lbs/yd ³ (1.8 to 3.0 kg/m ³)	Water Absorption	negligible
Available Lengths	¾" (19 mm), 1 ½" (38 mm)	Acid and Alkali Resistance	excellent
Aspect Ratio	39 / 79	Color	white
Tensile Strength	87-94 ksi (600 to 650 MPa)		

PACKAGING

TUF-STRAND MaxTen fibers are packaged in 3.0 lb (1.36 kg), 4.0 lb (1.81 kg) and 5.0 lb (2.27 kg) water soluble bags.

FIBER PRODUCTS

TUF-STRAND MAXTEN

MASTER FORMAT #: 032400

SHELF LIFE

3 years in original, unopened package.

DIRECTIONS FOR USE

TUF-STRAND MaxTen fibers can be added to the concrete mixture at any time prior to placement of the concrete. It is generally recommended to add any fiber material at the ready-mix concrete plant during batching. Fibers must be mixed with concrete for a minimum of three (3) to five (5) minutes at maximum mixing speed, depending on the mixer type, to ensure complete dispersion and uniformity. When adding 3 to 5 lbs/yd³ (1.8 to 3 kg/m³), a slump loss of up to 2" (50 mm) can be expected for a typical ready-mix concrete design. For higher dosages, increased loss in slump can be expected depending upon the mixture design. The use of water reducers and/or superplasticizers, such as Eucon 1037, Eucon MRX or the Plastol series of admixtures may be necessary to maintain desired workability.

Add other admixtures independently from fiber addition. TUF-STRAND MaxTen fibers are compatible with all Euclid Chemical admixtures. When used properly, and placed in a concrete mix of sufficient workability, the fibers will not adversely alter the compressive or flexural strength of concrete or shotcrete.

CLEAN-UP

Loose fiber material may be disposed in proper receptacles for refuse. Finishing equipment with fibers embedded in concrete should be thoroughly cleaned.

PRECAUTIONS/LIMITATIONS

- Use of fibers may cause an apparent loss in measured slump of concrete. This may be offset with the use of a water reducing admixture if necessary.
- Fibers should never be added to a "zero-slump" concrete. Ensure a minimum concrete slump of 3" (80 mm) prior to addition of any fiber material. Fibers may also be added in loose form to aggregate charging devices.
- In all cases, consult the Safety Data Sheet before use.

Rev. 11.14

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14. ABSTRACT The U.S. Army Engineer District, Memphis, uses the Richardson Landing mat casting field to produce articulated concrete mats that are tied together to form articulated concrete revetment “blankets” that are then placed on the riverbanks to serve as a form of erosion control. The Memphis District noted that the corners of some of these concrete mats were becoming damaged as the mats were moved from the casting field to the construction site. To combat this issue, the Memphis District, Construction Branch decided to incorporate synthetic fibers in the current concrete mixture proportion to bridge cracks induced by moving the concrete mats. However, there was concern that the addition of fibers would significantly reduce the workability of the concrete mixture, making it labor intensive to place in the forms and difficult to discharge the fresh concrete from transport vehicles at the casting field. The Memphis District contracted with the U. S. Army Engineer Research and Development Center's (ERDC's) Concrete and Materials Branch (CMB) to proportion three fiber-reinforced concrete mixtures containing 3-, 2-, and 1-lb/yd ³ , respectively, of synthetic (polypropylene) fiber into the current mixture proportion used at Richardson Landing mat casting field. The CMB performed aggregate testing, concrete trial batching, and hardened concrete strength testing to produce the new concrete mixture proportions. This interim report presents the results of testing conducted by the CMB as of 30 August 2016.						
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